Latest Paleocene benthic extinction event on the southern Tethyan shelf (Egypt): Foraminiferal stable isotopic ($\delta^{13}C$, $\delta^{18}O$) records

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ABSTRACT

The dramatic global extinction of 35%–50% of benthic foraminifera species in the deep sea in the latest Paleocene and associated negative excursions in $\delta^{13}C$ and $\delta^{18}O$ may be related to spreading of warm, saline bottom water from subtropical Tethyan shallow regions over the sea floor worldwide. Our study of neritic sections in Egypt shows that in the southern shallow Tethys, a prominent long-term change in bottom-water chemistry, sedimentation, and benthic foraminifera fauna was initiated at the time when the deep-sea benthic extinction event (BEE) took place. Bottom-water $\delta^{13}C$ values on the Tethyan shelf show a sudden 3.0‰ negative shift at this event; however, contrary to the deep sea, in which the $\delta^{13}C$ excursion was of short duration, Tethyan $\delta^{13}C$ values did not fully return to preboundary values, but remained depressed by ~1.5‰ for at least 1 m.y. The $\delta^{13}C$ values at the Egyptian shelf during the BEE are much lower than would be expected if this was a source region for global deep water. The $\delta^{18}O$ values indicate no significant change in bottom-water salinity or temperature at the BEE. The long-lasting environmental changes that began on the Egyptian shelf at the BEE may be related to, for example, gateway reorganization along the Tethyan seaway. Paleogeographic changes possibly also triggered a change in the loci of global deep-water formation; however, these loci must be sought in another part of the Tethys.

INTRODUCTION

Probably the most dramatic change in deep-sea benthic foraminiferal fauna during the past 90 m.y. occurred in latest Paleocene time (Miller et al., 1987; Kennett and Stott, 1990, 1991; Thomas, 1990). The most detailed studies of this event, at Ocean Drilling Program (ODP) Hole 690B on Maud Rise, off Antarctica, suggest that the benthic foraminiferal mass-extinction event occurred at the beginning of a short period (<100 ka) of unusual deep-water circulation (Kennett and Stott, 1991). During this event the temperature of Maud Rise bottom waters (2100 m paleodepth) rose from 9 °C to 16 °C, and $\delta^{13}C$ values declined by ~2.5‰. These changes may be related to a short-term change in the loci of global deep-water formation from southern high latitudes to subtropical regions. Shallow regions along the Tethyan seaway have been considered as particularly likely sources of sinking warm, saline deep water (Brass et al., 1982; Kennett and Stott, 1990, 1991; Barron and Peterson, 1991). In this study we compare isotopic records from the Egyptian part of the southern Tethyan shelf and Maud Rise, in order to further unravel the paleoceanographic changes that led to deep-sea foraminiferal extinctions.

GEBEL AWEINA AND GEBEL DUWI SECTIONS

The Paleocene Gebel Aweina and Gebel Duwi sequences accumulated on a broad North African shelf in an outer-neritic (150–200 m) and a middle-neritic (75–100 m) environment, respectively (Speijer and van der Zwaan, 1994; Speijer et al., 1996) (Fig. 1). Marlstone and shale dominate in the upper Paleocene and lower Eocene parts (nannofossil Zones NP9 and NP10) of these sections. In these and other Egyptian shelf sections, there is a distinct calcarenitic (20–40 cm thick), coprolite-rich bed (the benthic extinction event [BEE] bed), which can be traced into upper bathyal deposits in Israel and the Sinai Desert, where it coincides with the sudden disappearance of bathyal taxa such as *Gavelinella beccariiformis* (Speijer, 1995). At Aweina, several deeper-water species are also replaced by new ones at this bed (Speijer and van der Zwaan, 1994). At the shallower Duwi site, a gradual decline in benthic foraminiferal diversity just below the bed is followed by assemblages that are dominated by a few opportunistic species (Speijer et al., 1996). At Duwi, an unconformity (or several) is present just above the BEE bed, and a major part of upper Zone NP9 and possibly also lowermost NP10 is missing. At Aweina, the overall record is more complete; the BEE bed is in the middle of a 20-m-thick section assignable to Zone NP9. This stratigraphy corresponds well to ODP Hole 690B, where the BEE is also in the middle of NP9 (Aubry et al., 1996; Stott et al., 1996).

DIAGENESIS, VITAL EFFECTS, AND ISOTOPES

Stable isotopic studies on foraminifera from uplifted lower Paleogene sections (e.g., in Israel, Spain, Italy, Tunisia) are generally hampered by diagenetic problems. Although the foraminifera may appear excellently preserved, they are usually infilled by diagenetic calcite. This problem applies also to the Egyptian sections (Charisi and Schmitz, 1995); however, in the Duwi section we found a nearly continuous distribution of the large (1–3 mm), thick-shelled nodosariids *Frondicularia phosphatica* and *F. nakkadyi*, for which excellently preserved test walls could be separated from the diagenetic infilling calcite with a needle and ultrasound (Fig. 2). For the Aweina section, we use *Lenticulina* spp., although the test-

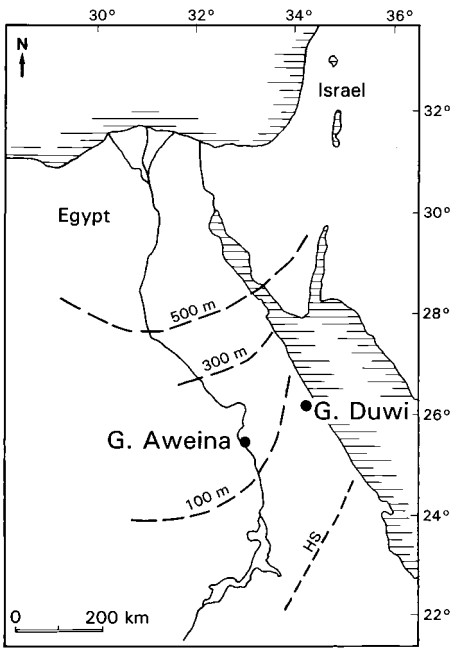

Figure 1. Location of studied sites in Egypt. Dashed lines indicate inferred paleobathymetry. HS indicates hypothetical shore line (see Speijer and van der Zwaan, 1994).

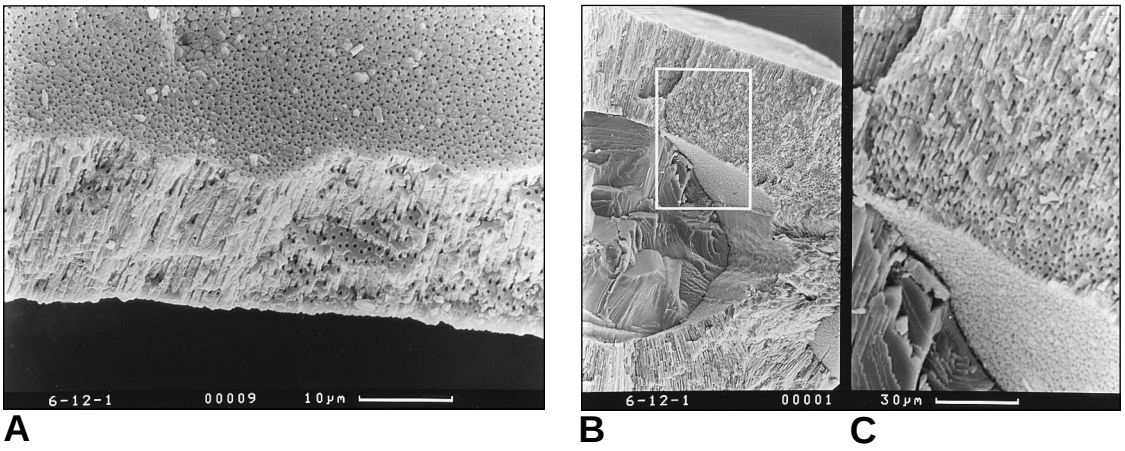

Figure 2. Fractured test of *Frondicularia* specimen from Duwi section. Chamber is completely infilled by diagenetic calcite (B), whereas small pores that traverse test wall lack infillings and are excellently preserved (A and C).

wall separation was more difficult. Separated diagenetic calcite shows $\delta^{18}O$ values of about −8‰ to −10‰; $\delta^{13}C$ values are similar to those in the bulk calcite.

When comparing different foraminiferal isotopic records, species-related vital effects and microhabitat isotopic variations (Grossman, 1987; McCorkle et al., 1990) must be considered. We have compared the isotopic composition of *Lenticulina* and *Frondicularia* at several stratigraphic levels in the sections discussed here. Assemblages of the two taxa from the same sample generally give similar isotopic results (Fig. 3), indicating the same equilibrium offsets and microhabitat preferences (most likely epifaunal to shallow infaunal; Corliss and Fois, 1991, and references therein). Foraminifera of the *Cibicidoides* taxa are considered to precipitate $\delta^{13}C$ generally in equilibrium with ambient dissolved inorganic carbon (Shackleton et al., 1984). In the Middle East sections, diagenetic calcite infillings prevent direct comparisons with *Cibicidoides*. However, in a study of the lower Eocene Røsnæs Clay Formation in Denmark, we have made detailed comparisons of very well preserved *Lenticulina* spp. and *Cibicidoides ungerianus* (Schmitz et al., 1996). We made comparisons at 13 stratigraphic levels representing a variety of different sea-floor conditions in a middle bathyal setting. *Lenticulina* gives negative offsets between 0.04‰ and 1.65‰ (mean = 1.08‰; S.D. = 0.51). This is the same range of $\delta^{13}C$ disequilibrium offsets as in recent *Lenticulina* in the compilation by Grossman (1987). For $\delta^{18}O$, *Lenticulina* is on average 0.2‰ (S.D. = 0.2) more positive than *C. ungerianus*; this value is also in good agreement with results for modern foraminifera (Grossman, 1987). *Cibicidoides* has a negative $\delta^{18}O$ disequilibrium offset of about 0.5‰ (Shackleton et al., 1984); accordingly, *Lenticulina* is quite close to equilibrium values. When comparing isotopic results from shelf and slope sections with those from the deep sea, we must also consider that sediment microhabitat heterogeneity, and isotopic variability, in general may be higher nearer the coast than in the more stable deep sea.

STABLE ISOTOPIC CHANGES

The foraminiferal $\delta^{13}C$ record at Aweina shows a conspicuous 3‰ negative shift at the BEE bed. At Duwi the shift is 2‰, probably reflecting the lower sample resolution across the BEE at this site. At both sites the $\delta^{13}C$ shift is preceded by a gradual negative change of ~1‰, starting about 5 to 10 m below the BEE bed (Fig. 3). At Aweina, just above the BEE bed there is a 1.5‰ $\delta^{13}C$ increase; however, subsequently, in the upper NP9 and lower NP10 part, values remain 1.0‰ to 1.5‰ lower than below the BEE bed. At Duwi, in the lower NP10 part, $\delta^{13}C$ values are similarly low.

The $\delta^{18}O$ values at Aweina and Duwi vary between −1.5‰ and −3.5‰; most values are in the range −2‰ to −3‰. Calculating paleotemperatures from the $\delta^{18}O$ data is complicated by the fact that salinity is not known. The $\delta^{18}O$ records from Egypt show no major change at the BEE bed, which probably reflects that there was no significant temperature or salinity change. A less likely alternative is that a combined warming and strong salinity increase is obscured by opposite effects of these processes on the $\delta^{18}O$.

The relative $\delta^{13}C$ changes across the benthic extinction horizon are quite similar in Egypt and ODP Hole 690B (Fig. 4). A major difference between the two records, however, is that whereas Maud Rise $\delta^{13}C$ values returned to almost preboundary values within ~100 ka after the BEE, values on the North African shelf remained persistently low for at least 1 m.y. The $\delta^{13}C$ values are also generally 1‰ to 3‰ more negative in Egypt than in Hole 690B. The Egypt–Maud Rise $\Delta\delta^{13}C$ difference is generally larger after the BEE than before. An intersite difference of ~2.5‰ is maintained also in connection with the BEE. This is important, because it appears to contradict that the deep waters at Maud Rise originated from the Egyptian shelf during this event. A Tethyan water mass moving to the Antarctic region would have "aged," showing lower $\delta^{13}C$ values at the Maud Rise than at the source area, because of addition of decomposing ^{12}C-enriched organic detritus. Instead, the opposite situation occurs: substantially lower $\delta^{13}C$ values on the southern Tethyan shelf than at the Maud Rise. The intersite difference in $\delta^{13}C$ can to some extent be accounted for by species-dependent vital effect or microhabitat differences; however, it is doubtful whether these processes can account for the entire 2.5‰ difference (plus a potentially aging-induced $\Delta\delta^{13}C$ difference). The parallelism of the two $\delta^{13}C$ records over the BEE indicates strong environmental perturbations, not only in the deep sea but also in the southern shallow Tethys.

Whereas the Maud Rise $\delta^{18}O$ values decrease over the BEE, suggesting a substantial warming, no similar trend is observed for $\delta^{18}O$ in Egypt. This difference may represent absence of a temperature increase in Egypt, which is consistent with $\delta^{18}O$ data for planktonic foraminifera from other low-latitude regions (e.g., Stott, 1992). These findings provide an argument against an enhanced greenhouse effect during the extinction event, since greenhouse warming would lead to both low and high-latitude heating (Rind and Chandler, 1991).

BEE ON THE SOUTHERN TETHYAN SHELF

Although our carbon isotopic data indicate that the Egyptian part of the southern Tethyan shelf did not supply the world

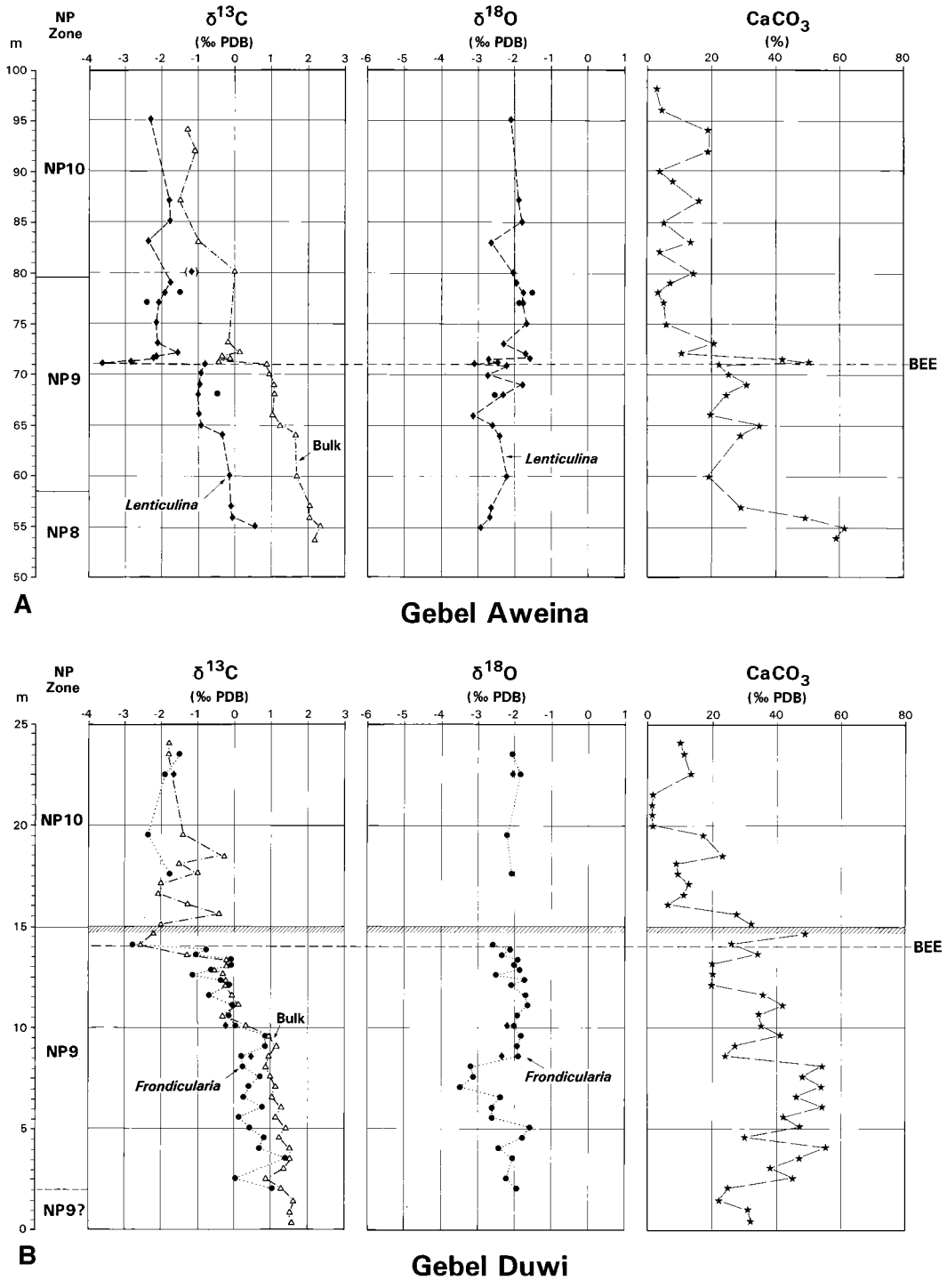

Figure 3. Stable isotopic and $CaCO_3$ results for Gebel Aweina and Gebel Duwi. BEE = Benthic extinction event. PDB = Peedee belemnite (for reference). Hachured line at 15 m in Duwi section indicates one or several unconformities. Metre levels for Aweina and Duwi sections show distances above Cretaceous-Tertiary boundary and base of studied interval, respectively. Circles in Aweina records represent measurements of *Frondicularia* specimens. Diamonds in Duwi records represent *Lenticulina* results. Each data point represents average of analyses of between 5 and 15 specimens. We used only *Lenticulina* specimens in the size fraction 250–500 μm and *Frondicularia* with lengths of 1–3 mm. Isotopic analyses were performed with VG Prism Series II mass spectrometer using routine procedures at Department of Marine Geology, Göteborg. Nannoplankton zonation after Martini (1971). At Duwi, a short interval of more negative $\delta^{18}O$ values about 6 m below BEE bed coincides with presence of more diversified benthic foraminifera fauna and more intensively bioturbated sediments (Speijer and van der Zwaan, 1994). This may be related to local or regional decrease in bottom-water salinity and decreasing density stratification of water column.

ocean with deep waters during the BEE, it cannot be ruled out that any other subtropical region along the Tethyan seaway provided the deep waters. However, if the deep-sea BEE merely reflects an episode of outflow of Tethyan waters worldwide, then the environmental changes would have been minor on the Tethyan shelves, but large in the deep-ocean areas where the Tethyan waters invaded. Our studies clearly show that a prominent persistent change in environmental conditions on the North African shelf was triggered coincidently with the deep-sea BEE. A new benthic foraminifera fauna indicative of higher nutrient levels settled on the shelves and persisted for at least 1 m.y. after the BEE (Speijer et al., 1996). There is also sedimentological evidence, such as a shift to calcite-poor shales, indicating increased corrosion in the water column (Fig. 3). Possibly the low post-BEE $\delta^{13}C$ values reflect intensification of the oxygen minimum zone near the sea floor and increased accumulation rates of decomposing organic detritus (see, e.g., Zahn et al., 1986). The surface and deep-water circulation in the Tethyan seaway may have changed in connection with the BEE, perhaps as a result of a sudden large-scale tectonic event, affecting an important sill or gateway. This hypothesis is consistent with modeling experiments suggesting that the sources of global deep water are sensitive to changes in geography. Changes affecting marginal, partially isolated regions, such as along the Tethyan seaway,

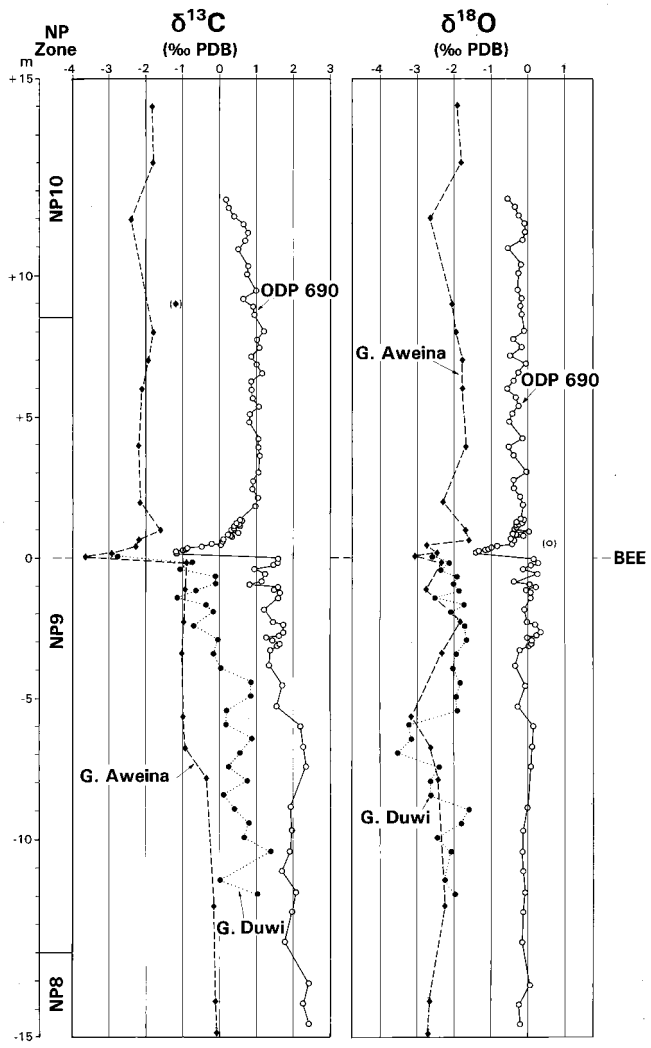

Figure 4. Comparison of foraminiferal isotopic results for Egyptian sections and ODP Hole 690B. Isotopic analyses in Hole 690B were made on assemblages of either *Nuttallides truempyi* or *Cibicidoides* spp. (Kennett and Stott, 1991; Stott et al., 1996). No corrections for vital-effect fractionation have been applied to any of the results. Relative stratigraphic position of samples has been established by interpolation, using NP8/NP9 and NP9/NP10 boundaries and benthic extinction event as reference levels (Aubry et al., 1996). Because of ongoing revisions of early Paleogene time scale, sample positions are given in depth (m), not time, reflecting sediment thickness in ODP Hole 690B, normalized relative sediment thickness in the Egyptian sections (i.e., reflecting hypothetical situation in which sedimentation rates were identical in the two regions).

may have particularly strong effects on the loci of deep-water formation (Barron and Peterson, 1991).

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